Problem Chosen	2025 MCM Summary Sheet	Team Control Number
B		2506401

Exploring a Sustainable Tourism Model for Juneau

Summary

With the rapid development of tourism, balancing economic growth with environmental protection and social benefits has become a critical challenge for global tourist destinations. Using Juneau as a case study, we developed two models to address its sustainable tourism challenges.

First, we established a **Sustainability and Productivity Evaluation Model (SPEM)** to assess the impacts of tourism on economic benefits, environmental costs, and social costs. The model includes two metrics: the **Sustainability Index** (Z), which evaluates the balance among economic, environmental, and social factors, and the **Economic Productivity Index (EPI)**, which quantifies tourism's economic contributions. Using a **feedback loop** and **dynamic programming framework**, we analyzed the relationships among tax policies, revenue allocation, tourist numbers, and conservation efforts. By integrating tourist numbers, average expenditure, and tax rates across different **consumption paths**, a comprehensive multi-dimensional evaluation model was developed. Additionally, we adopted an adaptive method to calculate indicator weights, ensuring accurate representation of their relative importance. Our findings indicate that rainforests are more sensitive to consumption and traffic. Glaciers are more sensitive to sightseeing and accommodation.. However, moderate tax increases can effectively mitigate the negative impacts of over-tourism on glaciers, achieving a balance between ecological protection and economic benefits.

Second, we proposed the **Sustainability and Productivity Genetic Optimization Model (SP-GOM)**, employing the **Non-Dominated Sorting Genetic Algorithm II (NSGA-II)** for dual-objective optimization of economic growth and environmental sustainability. A moderate solution from the Pareto frontier was selected to balance economic and social sustainability, resulting in an optimal tax rate τ scheme for all **consumption paths**. Findings suggest setting the overall tourism tax rate in Juneau to approximately 4.5% balances visitor numbers and conservation. Higher taxes (around 4.7%) on glacier tourism and lower rates for whale watching and rainforest tourism promote diversification and better resource allocation.

To enhance adaptability, we extended the framework by introducing a **household tax rate** variable to account for city-specific tax policies. This modification enables a more precise distribution of tourist activities and rational allocation of fiscal revenues, broadening the model's applicability to diverse urban contexts. What is more, we further applied our models to Bali and Barbala, demonstrating their potential to support balanced economic, environmental, and social development tailored to the unique needs of different destinations.

Sensitivity analysis identified tax adjustments and fiscal revenue allocation as key factors. Investments in transportation efficiency and ecosystem protection significantly improve resident satisfaction and support sustainable tourism. These insights provide actionable recommendations for Juneau and similar destinations.

Keywords: Sustainability Evaluation, consumption path, NSGA-II, Sensitivity analysis

Contents

1 Introduction

1.1 Problem background

Juneau, a small city in Alaska with a population of about 30,000, has experienced rapid growth in tourism, particularly from the cruise industry. In 2023, the city welcomed a record-breaking 1.6 million visitors, with daily peaks of up to 20,000 tourists. While this influx has generated approximately $ 375 million in revenue, it has also introduced significant challenges, including overburdened infrastructure, environmental degradation, community overcrowding, and an increased carbon footprint. Notably, the city's iconic Mendenhall Glacier is retreating rapidly due to climate change and overtourism, raising concerns that the loss of this natural attraction could severely impact Juneau's tourism appeal and economic benefits. Addressing these challenges while maintaining economic gains has become a critical issue, requiring scientific and sustainable approaches to manage tourism effectively.

1.2 Restatement of the problem

- **Develop a Model:** Construct a mathematical model for sustainable tourism that considers factors such as visitor numbers, city revenue, environmental preservation, and infrastructure capacity. Clearly define the optimization objectives and constraints, and propose a plan for allocating additional revenue to support sustainability initiatives.
- **Perform Sensitivity Analysis:** Conduct a sensitivity analysis on key variables and parameters within the model to evaluate their impact on optimization goals, identifying which factors are most critical for achieving sustainable development.
- **Adaptability of the Model:** Explore how the model can be adapted to other destinations impacted by overtourism. Adjust the model parameters and strategies to reflect the unique characteristics of different locations, and investigate ways to promote a balanced distribution of tourists to reduce overcrowding in popular hotspots.
- **Recommendations and Implementation:** Based on the model results, write a memo to provide actionable recommendations to the Juneau Tourism Council. Predict the outcomes of various management measures and develop a concrete action plan to improve tourism management strategies.

1.3 Literature review

With the rapid growth of global tourism, balancing economic development and ecological preservation has become a key challenge for researchers and policymakers. Previous studies have emphasized the importance of sustainable tourism management. Gowreesunkar and Seraphin (2019) highlighted strategies to mitigate over-tourism's effects, while Scott et al. (2012) explored how climate change impacts tourism, stressing the need for sustainable planning [3,4].

Optimization methods, such as NSGA-II, have been widely used in tourism management for multi-objective decision-making. Torres-Delgado and Saarinen (2015) stressed the critical role of indicator selection and weight distribution in determining optimization outcomes [5]. Dynamic programming has also proven effective in modeling trends and supporting long-term decisions.

Building on these foundations, this study integrates assessment and optimization models. The assessment model evaluates tourism's economic, environmental, and social impacts, while the optimization model employs NSGA-II to determine optimal tax rate combinations for sustainable development. Sensitivity analysis further ensures model robustness, enabling its application to diverse urban contexts. This research offers practical insights for global tourism's sustainable growth.

1.4 Our work

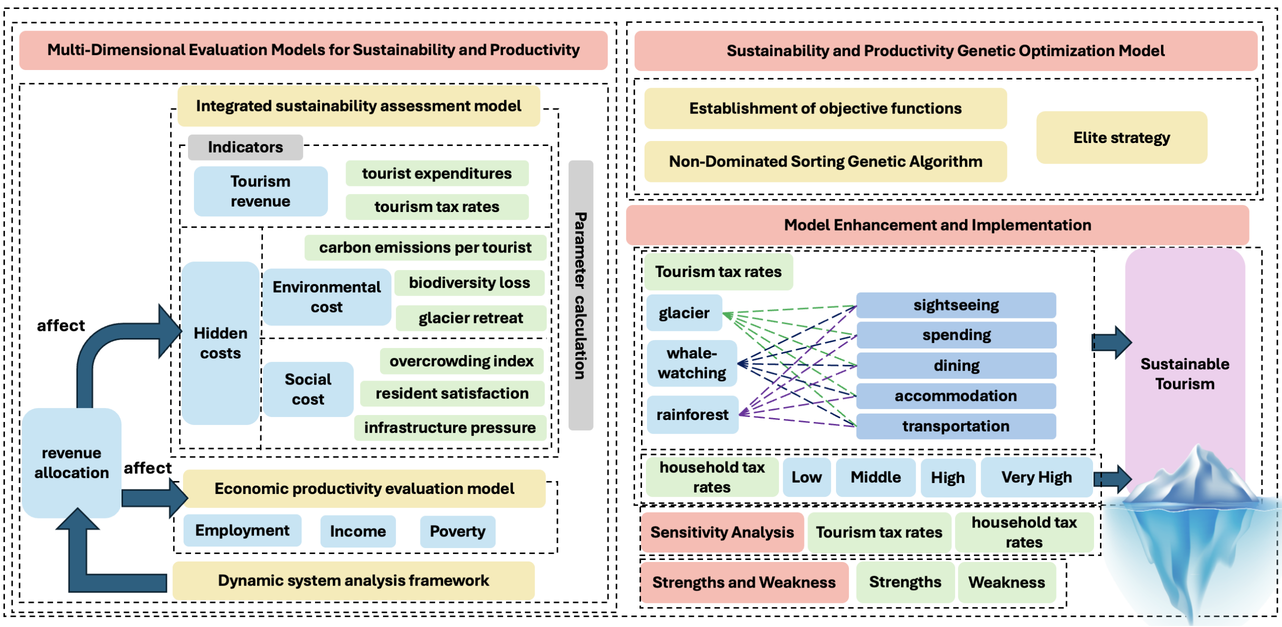


Figure 1: Our work overview schematic diagram

2 Preparation of the Models

2.1 Assumptions and Justifications

To simplify the problem and simulate real-world scenarios, we make the following assumptions, each with proper justification:

- **Assumption 1**: Data used in the model is accurate, reliable, and collected within a consistent timeframe.
  Justification 1: Accurate and consistent data ensures valid comparisons across environmental, economic, and social dimensions, forming a reliable basis for analysis.

- **Assumption 2**: Environmental impacts of tourism can be measured through carbon emissions, and natural attractions (e.g. glaciers, forests) exhibit self-recovery when human activity is controlled.
  Justification 2: Carbon emissions are a standard metric for environmental impact, and ecological studies show that ecosystems can recover when pressures are reduced, enabling an evaluation of the balance between tourism and conservation.

- **Assumption 3**: Policies like visitor taxes, limits, and environmental regulations are effectively enforced, and tax revenue is allocated to sustainability projects.
  Justification 3: Effective enforcement ensures the success of tourism management strategies, while prioritizing revenue for sustainability supports long-term development goals.

2.2 Notations

Table 1: Notations

Symbols	Description
R_{tourism}	Tourist revenue
$C_{\text{environment}}$	Environment cost
C_{social}	Social cost
EPI	Economic productivity index
Z	Sustainability Index
En_Th	Environmental threshold
Ocr_Th	Congestion threshold
G_0	Benchmark level of fiscal revenue
τ_i	Tourism tax rate charged by the government on the consumption path i
$E_{\text{total}}(\tau_i)$	Maximum employment capacity under tax rate τ_i
G_j	Tax rate charged by the government on household type j
I	Average income per family, per person
ΔP	Rate of poverty change
$E_i(t)$	Environmental degradation index of consumption path i at time t
$N_i(t)$	The number of tourists of consumption path i at time t
$S_i(t)$	The average amount spent by visitors of consumption path i at time t
$S_{(sat)i}(t)$	Resident satisfaction of consumption path i at time t

2.3 Data pre-processing

2.3.1 Data collection

To better explore the development of tourism in Juneau, we integrated data from the Alaska Tourism Industry Association and the "Travel Juneau" website. The dataset includes information on visitor activities, such as the number of tourists, their origins, and distribution patterns across key attractions like glaciers, whale watching, and rainforests. It also encompasses environmental indicators, including carbon emissions and the condition of tourist sites, as well as economic data related to tourist expenditures. Additionally, it provides insights into infrastructure development, such as water supply capacity and the availability of accommodation facilities, and outlines government policies, including tax regulations and measures aimed at environmental protection. By compiling this comprehensive dataset, we establish a solid foundation for analyzing the multifaceted impacts of tourism in Juneau and assessing the effectiveness of related policy interventions.

2.3.2 Filling Missing Data

During the collection of environmental indicators, missing values were identified for parameters such as greenhouse gas emissions, nitrous oxide emissions, and diesel particulate matter concentrations. To address this, we utilized ridge regression, which effectively leverages relationships among variables for imputation.

For example, to impute missing carbon dioxide (CO_2) emissions, we treated CO_2 as the target variable $\mathbf{y}$ and other complete features, such as greenhouse gas and nitrous oxide emissions, as input features $\mathbf{X}$. The ridge regression model was constructed with the following analytical solution:

$$\hat{\beta} = (\mathbf{X}_{\text{train}}^T \mathbf{X}_{\text{train}} + \lambda \mathbf{I})^{-1} \mathbf{X}_{\text{train}}^T \mathbf{y}_{\text{train}}, \tag{1}$$

where $\lambda > 0$ is the regularization parameter to mitigate multicollinearity and overfitting.

The optimal λ was selected using cross-validation, after which the model predicted missing values as:

$$\hat{\mathbf{y}}_{\text{test}} = \mathbf{X}_{\text{test}} \hat{\beta}, \tag{2}$$

where $\mathbf{X}_{\text{test}}$ represents the feature matrix for samples with missing CO_2 values.

This method ensured data consistency and preserved underlying variable relationships, improving the dataset's reliability for subsequent analysis.

2.3.3 Positive-Oriented Data Standardization

After initial data preprocessing, we categorized the indicators into positive and negative types. Positive indicators, such as employment rate, tourist expenditure, resident income, and satisfaction, improve sustainable development as their values increase. Negative indicators, like glacier melt rate and traffic congestion, negatively impact sustainability when their values rise.

To unify the scale of indicators with varying units, we applied the following standardization methods:

$$r_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \quad \text{(for positive indicators)}, \tag{3}$$

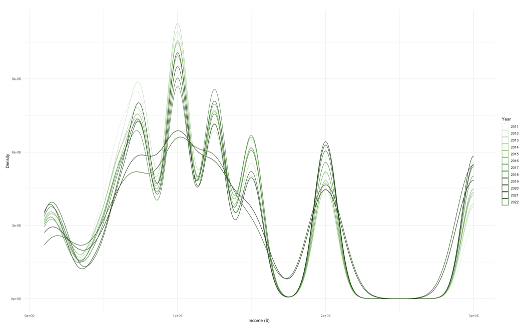
$$r_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} \quad \text{(for negative indicators)}. \tag{4}$$

This standardization process transformed all indicators onto a unified scale, ensuring that higher values consistently reflect better contributions to sustainable development, enhancing data comparability and interpretability.

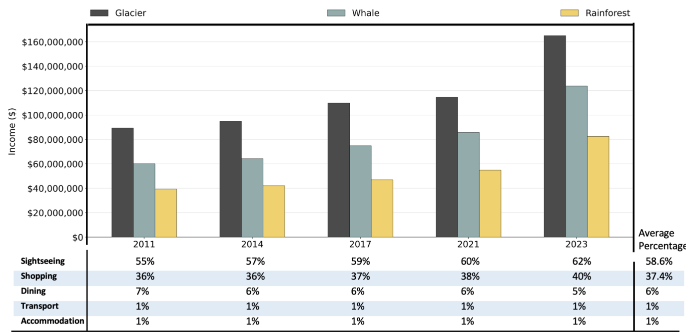
2.3.4 Data Visualization

Below is a visualization of some of the data we collected.

The figure left below shows the trend of the distribution of households with different incomes over time. From 2011 to 2022, the proportion of low-income households decreased year by year, while the proportion of high-income households increased year by year. It means that the development of tourism in Juneau region has indeed driven the increase of residents' income and gradually achieved sustainable economic development.



(a) Changes in household income distribution



	2011	2014	2017	2021	2023	Average Percentage
Sightseeing	55%	57%	59%	60%	62%	58.6%
Shopping	36%	36%	37%	38%	40%	37.4%
Dining	7%	6%	6%	6%	5%	6%
Transport	1%	1%	1%	1%	1%	1%
Accommodation	1%	1%	1%	1%	1%	1%

(b) Consumption distribution

Figure 2: Key data presentation

The figure right above shows the income proportion of Juneau's three consumption paths (glacier, whale watching and rainforest) over the years, as well as the consumption proportion of five overall consumption items (Sightseeing, Shopping, Dining and Transport). It can be seen from the income proportion of tourists on Juneau cruise ships. Over the years, tourists spend the most money on sightseeing, which shows that Juneau's natural scenery is the main factor attracting tourists. At the same time, the proportion of Juneau's income in luxury goods and souvenirs also increases year by year, showing that the consumption level of tourists is also increasing year by year. Besides, excluding the 2020 and 2021 years of Covid-19, the tourists of Juneau show continuous growth every year, which basically shows that Juneau is in line with sustainable development economically.

3 Sustainability and Productivity Evaluation Model

In recent years, the city of Juneau has encountered numerous challenges stemming from rapid tourism growth, including heightened pressure on infrastructure, environmental degradation, and declining resident satisfaction. Drawing on the data we collected, we developed a multi-dimensional evaluation models for sustainability and productivity that encompasses environmental, economic, and social dimensions to assess the current state of Juneau's tourism industry.

3.1 Sustainability-focused assessment model

3.1.1 Tourism revenue

Our tourism revenue primarily consists of tourist expenditures and government tax rates. By calculating tourist spending on glaciers, whale watching, and rainforests, as well as the tourism tax rates imposed by the government on different tourism industries, we derived the formula for calculating tourism revenue as follows:

$$R_{\text{tourism}} = \sum_{t=1}^{T} \sum_{i=1}^{n} \left(N_i(t) \cdot S(t) + \tau_i \cdot S(t) \cdot N_i(t) \right) \tag{5}$$

where $N_i(t)$ represents the number of tourists on the consumption path i in time t, $S(t)$ represents the average expenditure of tourists on path i in time t, and τ_i represents the tax rate charged by the government on the consumption path i.

By calculating tourists' direct expenditures across various tourism activities and incorporating the decision variable of "government tax rates," which we can adjust, we can not only evaluate the regulatory effects of tax rate adjustments on the tourism economy but also analyze the contributions of different tourism activities to the overall revenue structure. Moreover, the sector-specific revenue calculation approach captures the heterogeneity of tourism activities, providing a more precise basis for optimizing the tourism industry and allocating resources effectively.

3.1.2 Environmental cost

Environmental protection is a critical factor in ensuring the sustainable development of tourism in Juneau. With the increasing number of tourists, excessive use of tourism resources has gradually intensified environmental pressure, particularly the retreat of the Mendenhall Glacier. To better assess the sustainability of tourism, it is necessary to calculate the environmental costs associated with tourism activities. In doing so, we primarily consider carbon emissions per tourist, biodiversity loss, and glacier retreat to comprehensively quantify the multidimensional environmental impacts of tourism. The specific calculation formula is as follows:

$$C_{\text{environment}} = \sum_{t=1}^{T} \sum_{i=1}^{n} \left(\beta_1 \cdot P_{CO_2,i}(t) + \beta_2 \cdot \frac{1}{1+\tau_i} \cdot F_{\text{bio},i}(t) + \beta_3 \cdot E_{\text{ice\_loss},i}(t) \right) \tag{6}$$

where $P_{CO_2,i}(t)$ represents carbon emissions per unit of visitors on path i, which directly relates to the number of tourists, $F_{\text{bio},i}(t)$ represents the loss of biodiversity, which the government can mitigate by allocating tax revenues to biodiversity conservation efforts. Higher tax rates (τ_i) lead to stronger conservation measures, thereby reducing biodiversity loss. To reflect this relationship, we introduced a coefficient $\frac{1}{1+\tau_i}$ in front of the biodiversity loss term. $E_{\text{ice\_loss},i}(t)$ represents the amount of glacier degradation on path i, which will intensify when the number of tourists $N_i(t)$ increases. Moreover, β here represents the weight coefficient for each indicator, and its calculation process will be detailed in the following sections.

By introducing the ecological pressure component, we capture the sensitivity and stress levels associated with different tourism activities. Meanwhile, the resource consumption component indirectly reflects resource utilization efficiency and costs through tax rate adjustments.

3.1.3 Social cost

The social cost formula primarily measures the negative impacts of tourism on local communities. Based on the information we collected, social cost is divided into three components: overcrowding index, resident satisfaction, and infrastructure pressure, which can be expressed as follows:

$$O_{\text{crowd},i}(t) = \frac{N_i(t)}{\text{Capacity}_i} \tag{7}$$

$$R_{\text{res\_satisfaction},i}(t+1) = R_{\text{res\_satisfaction},i}(t) + \zeta_1 \cdot \tau_i \cdot R_i(t) - \zeta_2 \cdot O_{\text{crowding},i}(t) - \zeta_3 \cdot I_{\text{infra},i}(t) \tag{8}$$

$$I_{\text{infra},i}(t) = \frac{N_i(t)}{\text{Infrastructure\_limit}_i} \tag{9}$$

Here, $O_{\text{crowd},i}(t)$ represents the congestion index of path i, which is positively correlated with $N_i(t)$ and reflects the pressure of tourists on route resources and space, $R_{\text{res\_satisfaction},i}(t)$ represents residents' satisfaction with path i, which can be improved as more fiscal revenue is allocated to infrastructure development, and $I_{\text{infra},i}(t)$ represents the infrastructure pressure on path i, which is also positively correlated with $N_i(t)$, reflecting the increasing demand pressure of tourists on transportation, energy and public facilities.

By combining these three indicators, we can have our social cost as

$$C_{\text{social}} = \sum_{t=1}^{T}\sum_{i=1}^{n}\left(\gamma_1 \cdot O_{\text{crowd},i}(t) + \gamma_2 \cdot \frac{1}{1+\tau_i} \cdot R_{\text{res\_satisfaction},i}(t)) + \gamma_3 \cdot I_{\text{infra},i}(t) \cdot N_i(t)\right) \tag{10}$$

This formula identifies the main sources of social costs and establishes the relationship between government fiscal revenue and social costs, facilitating the discussion in subsequent sections on the role of tax expenditures in promoting sustainable tourism.

After completing the calculations for tourism revenue, environmental costs, and social costs, we can formulate our first objective function:

$$\begin{aligned}
Z_{max}(\tau) &= max\,\{R_{tourism} - C_{environment} - C_{social}\} \\
&= w_1 \cdot \frac{\sum_{t=1}^{T}\sum_{i=1}^{n}\left(N_i(t)\cdot S_i(t) + \tau_i \cdot S_i(t)\cdot N_i(t)\right)}{R_{\max}} \\
&\quad - w_2 \cdot \frac{\sum_{t=1}^{T}\sum_{i=1}^{n}\left[\beta_1 \cdot P_{\text{CO2},i}(t)\cdot N_i(t) + \beta_2 \cdot \frac{1}{\tau_i+1}\cdot F_{\text{bio},i}(t) + \beta_3 \cdot E_{\text{ice_loss},i}(t)\cdot N_i(t)\right]}{C_{\text{environment,max}}} \\
&\quad - w_3 \cdot \frac{\sum_{t=1}^{T}\sum_{i=1}^{n}\left[\gamma_1 \cdot O_{\text{crowd},i}(t)\cdot N_i(t) + \gamma_2 \cdot \frac{1}{\tau_i+1}\cdot R_{\text{res_satisfaction},i}(t) + \gamma_3 \cdot I_{\text{infra},i}(t)\cdot N_i(t)\right]}{C_{\text{social,max}}}
\end{aligned} \tag{11}$$

where, $R_{\max}$, $C_{\text{environment,max}}$, and $C_{\text{social,max}}$ represent the maximum values of tourism revenue, environmental costs, and social costs, respectively, as calculated in the previous sections.

3.2 Economic productivity evaluation model

In addition to optimizing the benefits brought by tourism, we also need to enhance our economic sustainability. To achieve this, we established an Economic Productivity Index (EPI) to evaluate the overall impact of tax policies on employment, income, and poverty across households with different income levels.

Considering the diminishing effect of employment rates, we assume that as government tax revenue allocated to tourism increases, the marginal contribution of additional employment to the total employment rate decreases. Therefore, we express the employment-related calculation in the following form: $1 - e^{-k_E \cdot \frac{E_j}{E_{\text{total}}(\tau_i)}}$, where $E_{\text{total}}(\tau_i)$ represents the maximum employment capacity on this consumption path i, which is associated with the tourism consumption tax rate τ_i.

Similarly, we take into account the positive effect of income, where an increase in household income fosters greater economic sustainability. To reflect this, we express the income-related calculation as $1 + k_1 \cdot \ln(1 + I_j)$, where k_1 denotes the income positive effect parameter, capturing the contribution of income growth to economic sustainability.

In the same way, considering the negative effect of poverty changes, we express the poverty-related component of economic sustainability as $1 - k_2 \cdot \Delta P_j$, where k_2 represents the poverty change negative effect parameter, quantifying the detrimental impact of poverty rate increases on economic sustainability.

By combining employment rates, employment levels, income, and poverty changes, we derive the formula for our Economic Productivity Index (EPI):

$$\mathrm{EPI} = \sum_{j=1}^{m} \left[\left(1 - e^{-k_E \cdot \frac{E_j}{E_{\text{total}}(\tau_i)}}\right) \cdot \left(1 - \frac{E_j}{E_{\text{total}}(\tau_i)}\right) \cdot \left(1 + k_1 \cdot \ln(1 + I_j)\right) \cdot \left(1 - k_2 \cdot \Delta P_j\right) \right], \tag{12}$$

where m represents the number of household income categories.

3.3 Constraint condition

To achieve the goal of sustainable development, we set an upper limit En_Th for environmental carrying capacity.

We assume that the environmental carrying capacity is linearly related to biodiversity and glacier area. Based on this assumption, the upper limit of our environmental carrying capacity at time t can be expressed as:

$$\mathrm{En\_Th}(t) = c_1 \cdot F_{\text{bio}}(t) + c_2 \cdot E_{\text{ice}}(t),$$

where c_1 and c_2 represent the impacts of biodiversity on the self-regulation capacity of the ecosystem and the effects of glaciers on the environmental carrying capacity respectively.

By consulting relevant literature and adjusting based on real-world conditions, we ultimately derived the environmental constraint as follows:

$$E_i(t) \leq \mathrm{En\_Th}(t),$$

Through extensive research and rigorous calculations, we have the following constraint conditions:

$$N_i(t) \leq N_{\max,i}(t) = c_3 \cdot C_{\text{environment}}(t)$$

$$0 \leq \tau_i \leq \tau_{\max}$$

$$\sum_{i=1}^{n} \tau_i \cdot S_i(t) \cdot N_i(t) \geq G_{\text{budget}}$$

3.4 Dynamic system analysis framework

3.4.1 Feedback loop model

To analyze how tourism revenue allocation influences sustainable development, we developed a feedback loop model to explore the dynamic interplay among environmental protection, social satisfaction, and economic returns, distinguishing between positive and negative feedback loops.

Positive feedback loops

$$R_i(t) \rightarrow \text{Protection} \rightarrow E_i(t+1) \downarrow \rightarrow S_{(sat)i}(t+1) \uparrow \rightarrow N_i(t+1) \uparrow \rightarrow R_i(t+1) \uparrow$$

Negative feedback loops

$$N_i(t) \uparrow \rightarrow O_{\text{crowd},i}(t) \uparrow \rightarrow S_{(sat)i}(t+1) \downarrow \rightarrow N_i(t+1) \downarrow$$

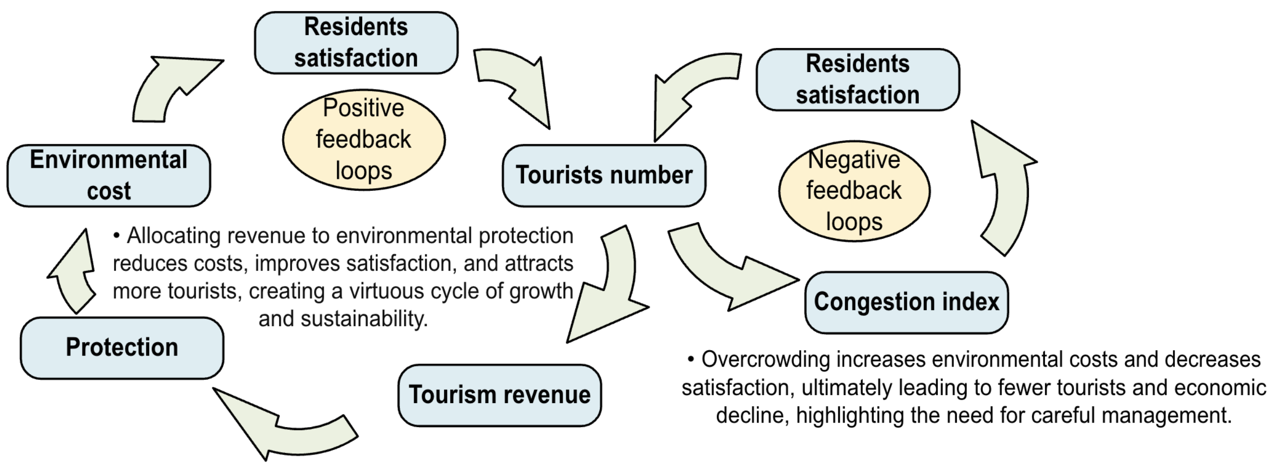


Figure 3: Feedback loop

3.4.2 Dynamic programming model

By developing a dynamic programming model, we analyze the evolution of key tourism indicators like revenue, environmental impact, and resident satisfaction. The model evaluates how regulatory measures, such as tax adjustments and environmental investments, influence the system's long-term stability, offering scientific support for policy-making and resource allocation.

Dynamic changes in the Environmental Degradation Indicator $E_i(t)$

We assume that the environmental degradation indicator is primarily influenced by tourist activities and tax revenue. The specific calculation formula is as follows:

$$E_i(t+1) = E_i(t) + \alpha_i \cdot N_i(t) - \beta_i \cdot \tau_i \cdot R_i(t) \tag{13}$$

where $E_i(t)$ represents the environmental degradation indicator of path i at time t, $N_i(t)$ denotes the number of tourists on path i at time t, and $R_i(t)$ represents the total revenue of path i at time t. The parameter α_i indicates the impact coefficient of each tourist on environmental degradation, while β_i reflects the effectiveness coefficient of tax investment in environmental protection.

Dynamic changes in tourist numbers

The dynamic change in tourist numbers is described by the following equation:

$$N_i(t+1) = \sigma N_i(t) \cdot \left(1 - \frac{E_i(t)}{\text{En\_Th}_i}\right) \cdot \left(1 - \frac{O_{\text{crowd},i}(t)}{\text{Ocr\_Th}_i}\right) \cdot (1 - \tau_i) \tag{14}$$

This equation captures the primary factors influencing changes in tourist numbers on each route:

- **Environmental impact**: As environmental degradation approaches or exceeds the destination's carrying capacity, fewer tourists are attracted due to declining environmental quality.
- **Overcrowding effect**: High levels of overcrowding reduce the destination's appeal, discouraging tourists from visiting and leading to a decline in tourist numbers.
- **Tax adjustments**: Increasing tourism taxes serves to regulate tourist numbers, mitigating the strain on local resources and environmental systems.

The coefficient σ accounts for external factors such as improved infrastructure, promotional efforts, and other developments that naturally drive tourist growth. By considering these factors, the model highlights the relationship between tourist numbers, environmental protection, and policy measures, providing a framework to balance growth with sustainability.

Dynamic Changes in Resident Satisfaction $R_{\textbf{res\_satisfaction},i}(t)$

Resident satisfaction reflects the social benefits of tourism development, influenced by taxation, overcrowding, and infrastructure pressure. Tax revenue allocated to public services and community improvements enhances satisfaction, while overcrowding and strained infrastructure reduce it. The dynamic change in resident satisfaction is calculated as:

$$R_{\text{res\_satisfaction},i}(t+1) = R_{\text{res\_satisfaction},i}(t) + \zeta_i \cdot \tau_i \cdot R_i(t) \tag{15}$$

This equation highlights the dual role of tourism revenue in improving quality of life and enhancing social benefits, balancing economic and social impacts on the community.

3.5 Parameter calculation

In our previous study, we proposed equations to describe dynamic interactions in the tourism system. However, undetermined parameters, like weight coefficients, affect validity. To address this, we calculate weights using eight methods: AHP, CRITIC, EWM, Weighted K-Means, MIM, VM, RM, and GRA. These methods ensure rigorous and practical weight distribution by analyzing indicator contributions from multiple perspectives.

And the optimal weight allocation scheme is obtained by setting the objective function:

$$min \sum_{k=1}^{m} ||W - W_k||^2$$

In this report, we use β_1, β_2, and β_3 in the environmental cost formula as examples for calculation and analysis.

3.5.1 AHP Weight Calculation

In the environmental cost formula, we assessed the relative importance of carbon emissions, biodiversity loss, and glacier retreat using the Analytic Hierarchy Process (AHP). The judgment matrix is as follows:

$$A = \begin{bmatrix} 1 & \frac{1}{3} & \frac{1}{5} \\ 3 & 1 & \frac{1}{2} \\ 5 & 2 & 1 \end{bmatrix}$$

By solving the judgment matrix, the largest eigenvalue is $\lambda_{\max} = 3.06$, and the weight vector is $W = [0.12, 0.26, 0.62]$. These weights are interpreted as follows:

- **Carbon emissions** ($\beta_1 = 0.12$): reflects a significant but less visible environmental impact.
- **Biodiversity loss** ($\beta_2 = 0.26$): highlights the importance of preserving ecosystems.
- **Glacier retreat** ($\beta_3 = 0.62$): represents the most critical factor due to its direct impact on Juneau's core tourism attractions.

The consistency of the matrix is verified:

$$CI = \frac{\lambda_{\max} - n}{n - 1} = 0.03, \quad CR = \frac{CI}{RI} = 0.05 < 0.1$$

Since $CR < 0.1$, the matrix is consistent. The final weights are:

$$\beta_1 = 0.12, \quad \beta_2 = 0.26, \quad \beta_3 = 0.62$$

3.5.2 CRITIC Weight Calculation

To objectively assign weights to carbon emissions, biodiversity loss, and glacier retreat, we applied the CRITIC method, which considers statistical variance and intercorrelations of indicators.

The standard deviation S_j of each indicator measures its variability:

$$S_j = \sqrt{\frac{\sum_{i=1}^{n} (a_{ij} - \bar{a}_j)^2}{n - 1}}, \tag{16}$$

where $\bar{a}_j$ is the mean of the j-th indicator. The correlation matrix r_{jk} captures redundancy among indicators:

$$r_{jk} = \frac{\sum_{i=1}^{n} (a_{ij} - \bar{a}_j)(a_{ik} - \bar{a}_k)}{\sqrt{\sum_{i=1}^{n} (a_{ij} - \bar{a}_j)^2} \cdot \sqrt{\sum_{i=1}^{n} (a_{ik} - \bar{a}_k)^2}}. \tag{17}$$

The information value C_j, which reflects an indicator's discriminative power, is given by:

$$C_j = S_j \cdot \sum_{k=1}^{n} (1 - r_{jk}). \tag{18}$$

Normalizing C_j yields the final weights:

$$\beta_1 = 0.4347, \quad \beta_2 = 0.2697, \quad \beta_3 = 0.2956.$$

This method ensures a scientifically grounded weight distribution, emphasizing the significance of carbon emissions due to their high variability and correlation with other indicators.

3.5.3 The rest of the weight algorithm results

The following table shows the results obtained by all the weight algorithms

Table 2: Local weight results in Environmental cost

Weight Calculation	AHP	CRITIC	EWM	K-Means	GRA	MIM	VM	RM
β_1	0.12	0.4347	0.191	0.1461	0.2874	0.1616	0.2606	0.3333
β_2	0.26	0.2697	0.4704	0.3903	0.3376	0.387	0.4575	0.3333
β_3	0.62	0.2956	0.3387	0.4637	0.375	0.4513	0.2819	0.3333

To enhance the scientific rigor and objectivity of weight distribution in this study, we optimize the weight redistribution by combining the results of different weight calculation methods (such as the entropy method, gray relational analysis, and variance method) into a single objective.

The objective function is defined as:

$$min \sum_{k=1}^{m} ||W - W_k||^2$$

Where W_k represents the weight vector calculated by the k-th method. W is the final integrated weight vector.

Then calculate the Euclidean distance between the comprehensive weights and each weighting method,and find the optimal weight method as:

$$\text{Best\_Method} = \arg\min_k d_k$$

In the weight calculation of environmental cost, we find that Grey Relational Analysis is the best algorithm.

Similarly, We obtained the weights $w_1, w_2, w_3$for tourism revenue, environmental costs, and social costs, respectively.

$$w_1 = 0.25,\ w_2 = 0.40,\ w_3 = 0.35$$

Thus, the global weight of second-level indicator can be calculate by: $w \cdot \beta$

Finally, We get the optimal weighting algorithm for each First-Level Indicator and summarized the weight coefficients calculated for all the indicators as follows:

Table 3: Weight Distribution for Sustainable Tourism Indicators

Goal	**First-Level Indicator**	**Second-Level Indicator**	**Local Weight**	**Global Weight**
Sustainable Tourism (U)	Tourism Revenue (U_1)	Tourist Consumption (U_{11})	0.6328	0.1582
		Government Tax Rate (U_{12})	0.3672	0.0918
	Environmental Costs (U_2)	Carbon Emissions per Capita (U_{21})	0.2592	0.1037
		Biodiversity Loss (U_{22})	0.3780	0.1512
		Glacier Retreat (U_{23})	0.3628	0.1451
	Social Costs (U_3)	Overcrowding Index (U_{31})	0.5782	0.2024
		Resident Satisfaction (U_{32})	0.2130	0.0745
		Infrastructure Pressure (U_{33})	0.2007	0.0702

4 Sustainability and Productivity Genetic Optimization Model

To balance sustainability and economic benefits in Juneau, we developed the **Sustainability and Productivity Genetic Optimization Model (SPGOM)** using the Non-Dominated Sorting Genetic Algorithm II (NSGA-II). SPGOM optimizes two key objectives: the Sustainability Assessment Model (Z) and the Economic Productivity Evaluation Model (EPI). This paper details the SPGOM process, including objective definition, population initialization, function calculation, non-dominated sorting, genetic operations, and result analysis.

4.1 Model objectives

At this stage, we have established two objective functions: $F_1(\boldsymbol{\tau})$ and $F_2(\boldsymbol{\tau})$.

$$F_1(\boldsymbol{\tau}) = Z_{max}(\boldsymbol{\tau}) = max\left\{R_{tourism}(\boldsymbol{\tau}) - C_{environment}(\boldsymbol{\tau}) - C_{social}(\boldsymbol{\tau})\right\}$$

$$F_2(\boldsymbol{\tau}) = \text{EPI} = \sum_{j=1}^{m}\left[\left(1 - e^{-k_E \cdot \frac{E_j}{E_{\text{total}}(\tau_i)}}\right) \cdot \left(1 - \frac{E_j}{E_{\text{total}}(\tau_i)}\right) \cdot \left(1 + k_1 \cdot \ln(1 + I_j)\right) \cdot \left(1 - k_2 \cdot \Delta P_j\right)\right],$$

The vector $\boldsymbol{\tau}$ represents the decision variables $(\tau_1, \tau_2, \tau_3, ..., \tau_{15})^\top$, where τ_1 to τ_{15} represent the tax ratio of path which is the combinations of three types of tourism activities (glaciers, whale watching, and rainforests) with five aspects (sightseeing, spending, dining, accommodation, and transportation).

4.2 Non-dominated Sorting Genetic Algorithm II (NSGA-II)

4.2.1Population initialization

After defining the objective functions, we proceed to initialize our population. The goal of this step is to generate a diverse set of candidate solutions, laying the groundwork for subsequent optimization.

Our initial population P_0 consists of a set of randomly generated candidate solutions, where each candidate represents a combination of tax rates:

$$x_k = (\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}, \tau_{12}, \tau_{13}, \tau_{14}, \tau_{15})$$

where τ_1 to τ_5 represent the tax rates for sightseeing, spending, dining, accommodation, and transportation in the Glacier route. Similarly, τ_6 to τ_{10} are the corresponding tax rates for the Whale-watching route, and τ_{11} to τ_{15} are for the Rainforest route. They are randomly chosen within the range $[5, 10]$. Subsequently, we randomly generate an initial population of size $N = 150$:

$$P_0 = \begin{bmatrix} \tau_{1,1} & \tau_{2,1} & \tau_{3,1} & \tau_{4,1} & \tau_{5,1} & \tau_{6,1} & \cdots & \tau_{13,1} & \tau_{14,1} & \tau_{15,1} \\ \tau_{1,2} & \tau_{2,2} & \tau_{3,2} & \tau_{4,2} & \tau_{5,2} & \tau_{6,2} & \cdots & \tau_{13,2} & \tau_{14,2} & \tau_{15,2} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ \tau_{1,N} & \tau_{2,N} & \tau_{3,N} & \tau_{4,N} & \tau_{5,N} & \tau_{6,N} & \cdots & \tau_{13,N} & \tau_{14,N} & \tau_{15,N} \end{bmatrix}$$

Finally, under the constraints described in Section 3.3, we validate the feasibility of each candidate solution in P_0. Any infeasible solutions are regenerated to meet the constraints.

4.2.2 Non-Dominated Relationship Analysis

In multi-objective optimization, the non-dominated relationship is defined based on the values of $F_1(x)$ and $F_2(x)$. Specifically, **Solution** A **dominates solution** B if and only if:

- $F_1(A) \leq F_1(B)$ and $F_2(A) \leq F_2(B)$
- At least one of the inequalities is strict: $F_1(A) < F_1(B)$ or $F_2(A) < F_2(B)$

Thus, solution A is closer to the Pareto-optimal front compared to solution B.

4.2.3 Non-Dominated Sorting

- The **first front** includes all solutions in the population that are not dominated by any other solution. These solutions are considered the current Pareto front.
- The **second front** is formed by removing the solutions of the first front and re-evaluating the dominance relationships among the remaining solutions.
- This process continues iteratively until all solutions are assigned to a specific front.

Each solution is assigned a **rank** based on its front: solutions in the first front are assigned Rank = 1, the second front Rank = 2, and so on. During the selection process, solutions in the lower-ranked fronts are prioritized.

4.2.4 Crowding distance calculation

To ensure that the population is uniformly distributed in the objective space, the **crowding distance** d_i is used to measure the sparsity of solutions. The calculation process is described as follows:

Firstly, to eliminate the dimensional differences of objective values, each objective function value is normalized using the following equation:

$$F'_k(x) = \frac{F_k(x) - F_k^{\min}}{F_k^{\max} - F_k^{\min}} \tag{19}$$

where $F_k^{\min}$ and $F_k^{\max}$ represent the minimum and maximum values of the objective F_k, respectively.

Next, for each solution x_i in the population, its crowding distance on objective k is calculated using the formula:

$$d_{i,k} = F'_k(i+1) - F'_k(i-1) \tag{20}$$

Finally, the total crowding distance for solution x_i is computed by summing up the crowding distances across all objectives:

$$d_i = \sum_{k=1}^{n} d_{i,k} \tag{21}$$

After calculating the crowding distance for each solution, it is stored as an additional attribute, serving as a secondary selection criterion in the genetic algorithm. Subsequently, selection, crossover, and mutation operations can be performed.

4.2.5 Elite strategy

Selection, Crossover, and Mutation

Tournament selection is first used to choose parent individuals. In each tournament, two individuals are randomly selected, with preference given to the one with a lower non-dominated rank. If ranks are equal, the individual with the larger crowding distance is chosen. The selected parents then

$$x_{\text{child}} = w \cdot x_{\text{parent1}} + (1 - w) \cdot x_{\text{parent2}} \tag{22}$$

where w is a random weight controlling the mixture ratio of the two parent solutions.

In addition, to enhance the diversity of the population, some variables of the offspring individuals are subjected to random mutations. This involves modifying τ_i or G_j to introduce perturbations, allowing the solutions to explore new regions in the search space.

Population Update and Next Generation Formation

The parent population P_t and the offspring population Q_t generated through crossover and mutation are combined to form a temporary population R_t:

$$R_t = P_t \cup Q_t \tag{23}$$

The temporary population has a size of $2N$. All individuals in R_t are re-ranked based on non-dominated sorting and crowding distance. The top N solutions are retained as the next generation population P_{t+1}. The following image illustrates the process of mutation and selection in the elite strategy through a flowchart.

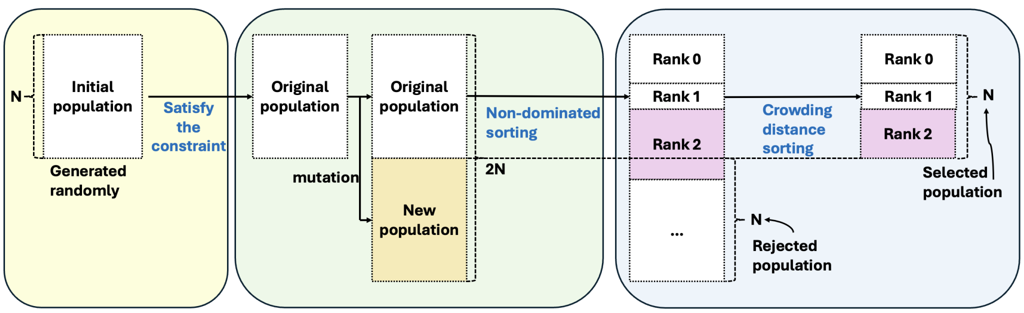


Figure 4: Flow chart of elite strategy

Figure 4 demonstrates that by employing the elite strategy for iterative calculations, the optimal solution for our model can be effectively determined. To provide a clearer understanding of the entire optimization process, we have represented it in the flowchart below.

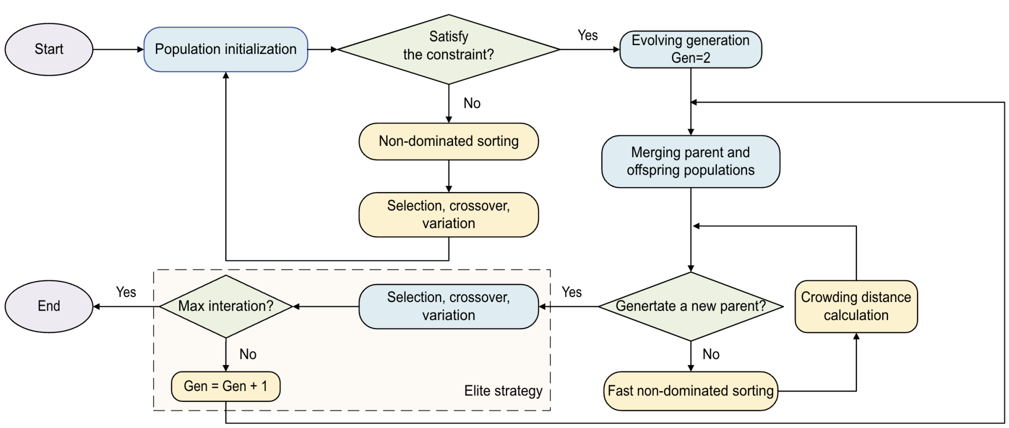


Figure 5: Flow chart of Genetic Optimization Model

Through genetic operations and population updates, NSGA-II optimizes the tax rate vector $\boldsymbol{\tau}$, converging to the Pareto-optimal front. The optimal tax decision $\boldsymbol{\tau}$ is then selected to promote sustainable tourism development.

4.3 Result display

The Sustainability Assessment Model (Z) and Economic Productivity Evaluation Model (EPI) were integrated into NSGA-II, producing the following results:

The left graph shows the Pareto frontier. Points on the right prioritize Z (environmental sustainability), while points on the left favor EPI (economic sustainability).

The highlighted point represents the balanced optimal solution, combining Z and EPI to identify the optimal tax rate.

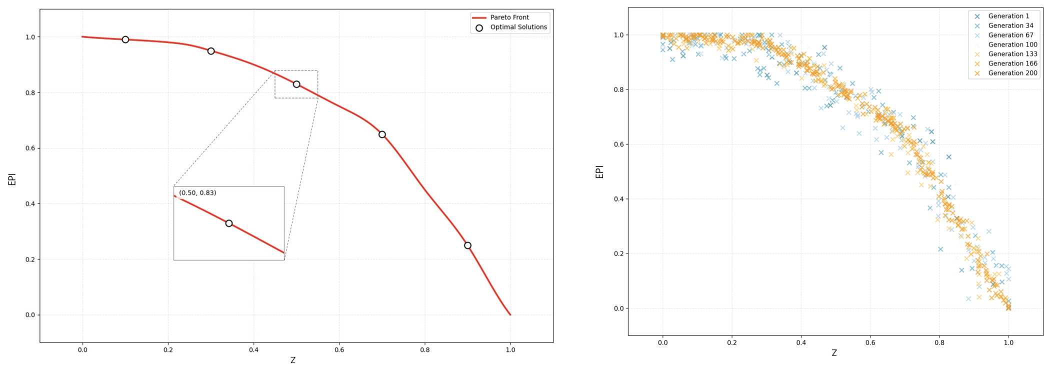


Figure 6: Pareto frontier plot and its evolution pattern

The diagram above shows the population evolution process, with points in different colors representing generational distributions. Over iterations, the population converges to the Pareto frontier, indicating NSGA-II's approach to the optimal solution. The uniform solution

Each Pareto solution $\boldsymbol{\tau_k}$ and its corresponding objective function values $[F_1(\boldsymbol{\tau_k}), F_2(\boldsymbol{\tau_k})]$ are shown in the table below:

Table 4: The Exact Value of the Pareto Solution

Solution ID	$F_1(\boldsymbol{\tau})$	$F_2(\boldsymbol{\tau})$	Project	Tax ratio combination $\boldsymbol{\tau}$
Solution 1	0.1324	0.9901	Glaciers Whale Watching Rainforests	(4.79, 5.54, 4.98, 5.93, 4.9) (4.85, 5.9, 5.61, 4.85, 4.99) (5.11, 5.17, 5.6, 5.07, 5.05)
Solution 2	0.3223	0.9552	Glaciers Whale Watching Rainforests	(4.7, 4.29, 4.32, 4.47, 4.72) (4.74, 4.44, 4.48, 4.43, 4.21) (4.8, 4.34, 4.28, 4.49, 4.31)
Solution 3	0.5225	0.8357	Glaciers Whale Watching Rainforests	(4.66, 4.49, 4.33, 4.77, 4.31) (4.39, 4.31, 4.62, 4.6, 4.26) (4.56, 4.41, 4.78, 4.5, 4.71)
Solution 4	0.7983	0.6583	Glaciers Whale Watching Rainforests	(4.36, 4.34, 4.55, 4.58, 4.77) (4.62, 4.43, 4.79, 4.74, 4.57) (4.56, 4.25, 4.71, 4.61, 4.4)

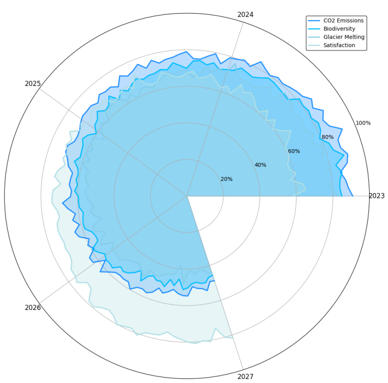
The vector $\boldsymbol{\tau}$ represents the decision variables $(\tau_1, \tau_2, \tau_3, ..., \tau_{15})^\top$, where τ_1 to τ_{15} represent the tax ratio of path which is the combinations of three types of tourism activities (glaciers, whale watching, and rainforests) with five aspects (sightseeing, spending, dining, accommodation, and transportation).

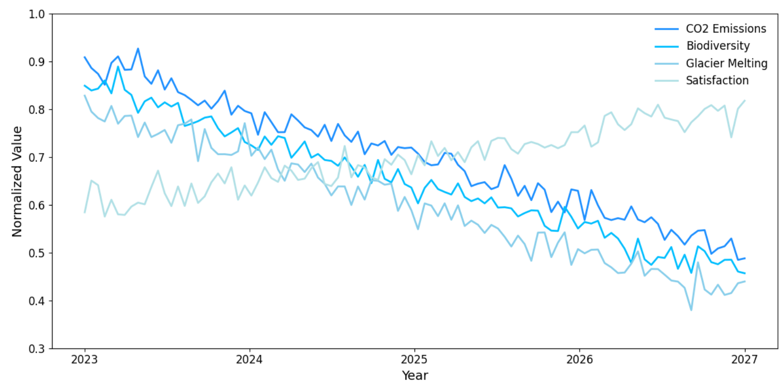
From the results, we can see that the tax distribution in rainforest has a more obvious impact on F_1, glaciers are more sensitive to F_2, and Rainforests are more sensitive to consumption and traffic. Glaciers are more sensitive to sightseeing and accommodation. From different schemes, the proportion of catering changes little and has no significant impact on the objective function, which is a relatively stable factor.

In the current model we choose solotion3 as our exchange rate adjustment decision, where both objective functions reach acceptable levels.

4.4 A simulation for following 5 years

In order to test whether our optimization results are in line with sustainable development, we simulated income, tax revenue, tourist number distribution, biodiversity change, resident satisfaction and other indicators in the next five years. We found that the current optimization results can promote sustainable development in the next few years, as shown in the radar chart below





As can be seen from the line chart, under the simulation of our optimization model, if we invest our tax into environmental governance and infrastructure construction, our environmental factors can be effectively alleviated, greenhouse gas emissions can be curbed, glacier melting rate can be reduced, and residents' satisfaction can be increased, which indicates that our model can achieve sustainable development in terms of environmental and social factors.

5 Sensitivity Analysis

The complexity of the model is often high when we have included multiple tourism routes, different proportions of tourism tax rates, and a variety of environmental impact indicators.

Sensitivity Analysis is used to evaluate the impact of parameter changes on system outcomes and identify the most influential parameters.

In this study, baseline tax rates are $r_0 = (0.03, 0.06, 0.03)$ for Glacier, Whale, and Rainforest. Outputs are calculated based on tourists' price sensitivity and environmental capacity.

Using r_0 as the baseline, we introduce a small perturbation to one component r_i while keeping others constant and observe the resulting change in output Y.

$$S_{Y_j}(r_i) \approx \frac{F_j(r_1, \ldots, r_i + \Delta, \ldots, r_n) - F_j(r_1, \ldots, r_i, \ldots, r_n)}{\Delta}$$

Here, Δ is a relatively small increment. The calculated result represents the Path i Sensitivity.

In the table, we display ΔY_j in terms of absolute values or relative changes and use threshold labels such as Low, Medium, High to characterize the impact levels. The results are as follow.

Table 5: Impact of Tax Changes on Absolute Tourist Numbers

Path	Initial Tourists	Initial Tax Rate	Tax +5% Impact	Tax +10% Impact
Glacier Route	300,000	3.0%	-19,984	-107,183
Whale Route	200,000	6.0%	-74,803	-139,112
Rainforest Route	150,000	3.0%	-18,557	-99,527

Table 5 indicates that when the tax rate increases by 1%, Glacier Route experiences a reduction of approximately 4,158 tourists, Whale Route sees a decrease of around 3,960 tourists, and Rainforest Route loses approximately 3,861 tourists.

For higher tax rate adjustments, the impact becomes even more significant, particularly under the 5% and 10% scenarios. This difference highlights varying levels of sensitivity across routes, which will be analyzed in next table.

Table 6: Impact of Tax Changes on Relative Tourist Shares

Path	Initial Share	Tax +1% Change	Tax +5% Change	Tax +10% Change
Glacier Route	46.2%	-1.4%	-6.7%	-35.7%
Whale Route	30.8%	-2.0%	-37.4%	-69.6%
Rainforest Route	23.1%	-2.6%	-12.4%	-66.4%

Table 6 shows that with a 5% or 10% tax increase, the **Whale Route** and **Rainforest Route** experience larger declines in tourist shares than the **Glacier Route**. This is because the Glacier Route offers a unique, irreplaceable experience, making it less price-sensitive. In contrast, the Whale and Rainforest Routes attract more price-sensitive tourists due to their substitutability. The **Tax Elasticity Coefficients** reflect the sensitivity of visitor numbers to tax changes:

$$\text{Glacier Route: } 1.39, \quad \text{Whale Route: } 1.98, \quad \text{Rainforest Route: } 2.57$$

The lower elasticity of the Glacier Route suggests that its visitor demand is less affected by tax increases, while the higher elasticities for Whale and Rainforest Routes signify greater responsiveness to price changes.

5.1 The most important factor

The tax rate allocation for the three routes considers their characteristics and demand elasticity:

The **Glacier Route**, with low price elasticity (1.39) and unique appeal, can sustain higher taxes. Recommended rates are **+7.8%** for environmental protection and **+3% to +5%** for revenue stability, reflecting tourists' willingness to pay for glacier conservation.

The **Whale Route**, with higher elasticity (1.98), requires lower rates (**+1% to +3%**) to avoid significant visitor loss. A **+5%** cap is advised for environmental goals.

The **Rainforest Route**, with the highest elasticity (2.57), needs careful tax adjustments. Suggested rates are **+1% to +3%** for stability, with **+5%** as the maximum for environmental objectives.

This strategy balances environmental protection, revenue stability, and route characteristics, supporting sustainable tourism. Our tax strategies are summarized as follows:

Table 7: Recommended Tax Rates by Route and Goal

Goal	**Glacier Route**	**Whale Route**	**Rainforest Route**
Environmental Protection	+7.8%	+5%	+5%
Revenue Stability	+3% to +5%	+1% to +3%	+1% to +3%
Localized Regulation	+0.3% to +1%	—	—

6 Model Enhancement and Implementation

6.1 Economic productivity evaluation model enhancement

We aim to expand our model to other cities. While Juneau has no personal income tax, other regions may impose such taxes. To enhance adaptability, we've added household tax rates as a variable, allowing the model to account for regional tax differences. Our sustainability assessment model remains unchanged, but the economic productivity evaluation (EPI) now classifies households into four income categories—Low, Middle, High, and Very High—based on annual income data. The classification criteria are as follows:

Table 8: Classification of households by income

Household Type	Low	Middle	High	Very High
Annual Income ($)	$\leq 24,999$	24,999–74,999	75,000–149,999	$\geq 150,000$

Thus, we have updated our Economic Productivity Evaluation Model (EPI) as follows:

$$\mathrm{EPI} = \sum_{j=1}^{m} \left[\frac{G_j}{G_0} \cdot \left(1 - e^{-k_E \cdot \frac{E_j}{E_{\text{total}}(\tau_i)}}\right) \cdot \left(1 - \frac{E_j}{E_{\text{total}}(\boldsymbol{\tau})}\right) \cdot \big(1 + k_1 \cdot \ln(1 + I_j)\big) \cdot \big(1 - k_2 \cdot \Delta P_j\big) \right], \tag{24}$$

where G_j represents the tax rates for four income levels: Low, Middle, High, and Very High households.

By adjusting the tourism tax rate combination $\boldsymbol{\tau}$ and the household tax rate G_j, we can increase revenue, create job opportunities, and reduce poverty, thereby promoting economic development.

6.2 Genetic optimization model enhancement

After incorporating household tax rates, the candidate tax rate combinations in our population P_0 were updated to:

$$x_k = (\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}, \tau_{12}, \tau_{13}, \tau_{14}, \tau_{15}, G_1, G_2, G_3, G_4)$$

while the range of τ remains unchanged, still set to $[5, 10]$, the range of G_j is set to $[3, 15]$ based on relevant references.

Subsequently, we generated a new corresponding initial population:

$$P_0 = \begin{bmatrix} \tau_{1,1} & \tau_{2,1} & \cdots & \tau_{13,1} & \tau_{14,1} & \tau_{15,1} & G_{1,1} & G_{2,1} & G_{3,1} & G_{4,1} \\ \tau_{1,2} & \tau_{2,2} & \cdots & \tau_{13,2} & \tau_{14,2} & \tau_{15,2} & G_{1,2} & G_{2,2} & G_{3,2} & G_{4,2} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \tau_{1,N} & \tau_{2,N} & \cdots & \tau_{13,N} & \tau_{14,N} & \tau_{15,N} & G_{1,N} & G_{2,N} & G_{3,N} & G_{4,N} \end{bmatrix}$$

The remaining operations are consistent with the previous sections, allowing us to optimize sustainable tourism development for different regions.

6.3 Model application in over-tourism and mild-tourism city

Our model considers three routes: Glacier, Whale Watching, and Rainforest Trekking, with Juneau as an overtourism case. To test generalizability, we chose **Bali** (overtourism) and **Santa Barbara** (mild tourism).

In 2023, **Bali** received **5,273,258 visitors**, with an average expenditure of **$188**, similar to Juneau. Issues include waste management, water scarcity, and traffic congestion.

Santa Barbara hosts **650,000 visitors** annually, with an average expenditure of **$266.16**. Challenges include limited accommodation, sea-level rise, and climate warming.

Table 9: Tourism Data for Cities

City	2023 Visitors	Average Spending (USD)	Total Revenue (USD)	Population
Bali	5,273,258	188	14.6 billion	4,400,000,000
Santa Barbara	650,000	266.16	242.9 million	86,499

Our model has been adapted to reflect Bali's unique tourism industry. Unlike the original framework, which included routes like "Glacier Tours" and "Whale Watching," we redefined the routes as Volcano Path, Beach Path, and Cultural Tour to align with Bali's attractions. Environmental issues such as coral reef degradation and infrastructure damage are also incorporated.

Similarly, for Santa Barbara, we focus on Beach, Cultural Tour, and Hiking paths, addressing issues like rising sea levels, overcrowding, and marine pollution. To tackle these challenges, we regulate tourist numbers and implement tax strategies. Due to space limitations, only Bali's tax strategies for the three paths are shown.

Table 10: Overall Tax Rates for Bali by Path

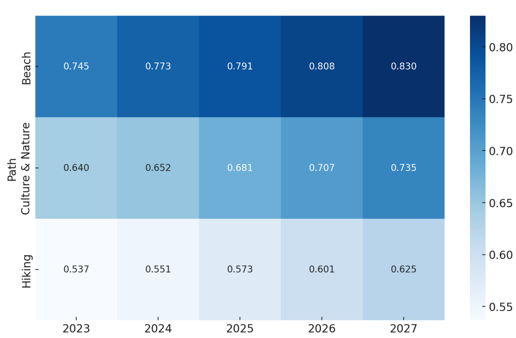
Year	**Path 1 (Beach Tourism)**	**Path 2 Cultural tours**	**Path 3 (Hiking)**
2023	6.00%	4.00%	3.00%
2024	5.53%	3.17%	2.93%
2025	4.76%	2.67%	3.18%

After combining all the conditions in bali and Barbala, our suggestions and optimization results for theses two cities are shown as following.

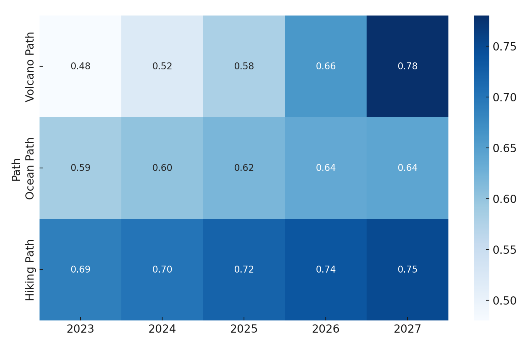
Table 11: Simulation for Santa Barbara and Bali

Simulation	P1 Tourists Num	P2 Tourists Num	P3 Tourists Num	Sustainability Index
Santa 2023	2,160,000	1,444,000	600,000	0.7667
Santa 2025	2,150,487	1,400,314	598,179	0.8857
Santa 2025	2,0234	1,341,684	548,013	0.9440
Bali 2023	2,272,966	1,445,640	654,651	0.7799
Bali 2025	2,300,293	1,596,223	1,102,960	0.8921
Bali 2027	2,698,850	2,125,551	1,167,735	0.9472

As shown in the table, out optimization model records the changes of numbers of tourists and the sustainability index, it shows that though number of tourists decreases for first several years, the sustainability shows an steady increasing and we concludes that the taxes has been effectively put into the environmental governance, and the overall revenue is still guaranteed so it shows a sustainable development.



(a) Optimization for Barbala



(b) Optimization for Bali

Figure 8: The changes of sustainability index in two tourism cities

The tax strategies for Bali and Barbala have been effectively applied to environmental governance and infrastructure development. Figure 8 demonstrates that our model balances these demands effectively.

For popular tourist hotspots, where visitor demand is less price-sensitive, adjusting tax rates can generate additional revenue to address environmental issues. By modifying taxes on entry tickets, consumption, and related expenses, sufficient funding can be allocated for environmental management.

7 Model Evaluation and Further Assumption

7.1 Strength

- This study divides Juneau's tourism consumption into 15 paths and designs targeted tax strategies, enhancing understanding of consumer spending behavior and tourists' tax sensitivity. This improves the government's precision and flexibility in managing tourism.
- Using unsupervised weighting algorithms, this study constructs an objective function to identify optimal weight combinations. This ensures rigorous evaluation by retaining maximum information from the original data.
- Given the complexity of the objective functions and constraints, NSGA-II effectively handles input conditions. It produces a high-quality Pareto front with uniform distribution, diversity, and near-optimal solutions, making it ideal for multi-objective optimization.
- We enhanced the assessment and optimization models by incorporating the household tax rate variable, making them more adaptable to diverse tax policies and socio-economic contexts. This improvement enhances the models' accuracy in evaluating tourism impacts and provides tailored recommendations for policy and resource allocation, increasing their applicability.

7.2 Weakness

- While such policies theoretically promote sustainable tourism, their complexity and frequent adjustments may confuse tourists, potentially reducing visitor numbers. This factor was not considered in the model.

8 References

1. Alaska Tourism Industry Association. (n.d.). *Research and reports*. Retrieved January 24, 2025, from `https://www.alaskatia.org/resources/research`
2. Travel Juneau. (n.d.). *Tourism works*. Retrieved January 24, 2025, from `https://www.traveljuneau.com/tourismworks/`
3. Gowreesunkar, V., & Seraphin, H. (2019). Introduction: What smart and sustainable strategies could be used to reduce the impact of overtourism? *Worldwide Hospitality and Tourism Themes, 11*(5), 1-15.
4. Scott, D., Hall, C. M., & Gössling, S. (2012). *Tourism and climate change: Impacts, adaptation, and mitigation*. Routledge.
5. Torres-Delgado, A., & Saarinen, J. (2015). Using indicators to assess sustainable tourism development: A review. In *New research paradigms in tourism geography* (1st ed., pp. 1-17). Routledge.

To: Juneau Tourism Council

From: Team 2506401

Date: January 27, 2025

Dear Juneau Tourism Council,

It is my honor to share our research findings with you. We developed two models to address sustainable tourism in Juneau: the Sustainability-Focused Assessment Model, which evaluates economic, environmental, and social factors, and the Sustainability and Productivity Genetic Optimization Model, which identifies strategies for balancing growth and sustainability. Together, these models offer actionable insights for promoting sustainable tourism.

Sustainable tourism aims to balance economic growth, environmental protection, and community well-being, ensuring resources are preserved for future generations. By following sustainable practices, tourism can create a positive cycle where increased revenue supports environmental conservation and community development, enhancing a destination's appeal and driving further growth. For Juneau, this approach is vital to safeguarding its natural and cultural resources while achieving long-term benefits for both residents and visitors.

Next, let me explain how adjusting tax policies and reallocating fiscal revenue can promote the sustainable development of Juneau's tourism industry.

- **Optimize Tourism Tax Rates to Manage Visitor Flow**
  Given the lower price sensitivity of glacier tourism, increase the tax rate for glacier-related activities to around 4.5%, with slightly higher rates of approximately 4.7% for accommodation and transportation. This adjustment can help mitigate the environmental pressures caused by overtourism, such as glacier degradation. At the same time, reduce the tax rates for whale-watching and rainforest routes to encourage visitor redistribution and promote the diversification of tourism resources.
- **Invest in Infrastructure Development While Enhancing Resident Satisfaction**
  Prioritize the allocation of tourism revenue to improve transportation efficiency and protect ecological systems, as these areas yield the highest long-term benefits for the tourism industry. Additionally, enhance public services, optimize waste management facilities, and expand visitor capacity to minimize the negative impact of tourism on local residents. By fostering greater support and involvement from residents, a positive feedback loop can be created, benefiting both the community and the tourism sector.
- **Balance Economic Growth with Environmental Preservation**
  Implement policies that achieve a balance between economic productivity and environmental protection. Measures such as setting visitor caps, promoting green tourism initiatives, and increasing investments in ecological preservation can help prevent overdevelopment and resource depletion. These efforts ensure both sustained economic benefits and the long-term protection of Juneau's natural environment, supporting the overall sustainability of its tourism industry.

Thank you for reviewing our work. We admire your efforts to balance economic growth with environmental preservation and hope our models provide valuable insights for Juneau's tourism strategy. Feel free to reach out with any questions—we look forward to seeing Juneau set a benchmark for sustainable tourism.

Yours Sincerely,
Team 2506401